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October 19, 2017

VIA ELECTRONIC FILING

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: Written *Ex Parte* Notice, GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95; RM-11664; and WT Docket No. 10-112

Dear Ms. Dortch:

The Boeing Company ("Boeing"), through its counsel, hereby files the attached technical discussion regarding spectrum sharing considerations in the 37.5-40.0 GHz portion of the V-band between individually-licensed satellite earth stations and networks operating in the Upper Microwave Flexible Use Service ("UMFUS"). The attached paper provides comments on the recent *ex parte* submissions of Viasat[1] and Inmarsat/SES-O3b[2] regarding the protection distances that individually-licensed satellite earth stations would require in order to successfully coexist with UMFUS.

Boeing believes that the engineering analysis provided by Viasat and the analysis provided in the ITU Task Group 5/1 paper that was submitted by Inmarsat and SES/O3b were each based on valid assumptions and employ appropriate technical analysis that fully support the conclusions that were reached in each paper. Boeing believes, however, that some of the assumptions that were employed in the TG 5/1 paper were unnecessarily conservative and, as a result, a separation distance of less than half of the 1,100 meters specified in the TG 5/1 paper would be sufficient to adequately protect satellite earth stations in most conditions. These separation distances could be reduced even further through the use of natural or artificial shielding of satellite earth stations, as validly reflected in the paper that was submitted by Viasat.

Given the relatively close proximity that is achievable between individually-licensed satellite earth stations and UMFUS deployments, Boeing urges the Commission to employ

[1] Letter from John. P Janka, outside counsel to Viasat, Inc. to Ms. Marlene Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-77, *et al.* (Oct. 2, 2017).

[2] Letter from G. Creeser (Inmarsat Inc.), G. Oberst (SES Americom), and S. Malloy (O3b Limited) to Ms. Marlene Dortch, Secretary , Federal Communications Commission, GN Docket No. 14-77, *et al.* (Oct. 12, 2017).

significantly more flexibility in the manner in which satellite earth stations are permitted to operate in the 37.5-40.0 GHz band. Specifically, the Commission should withdraw as unnecessary its limit of three satellite earth stations per Partial Economic Area ("PEA"). The Commission should also adopt rules that allow satellite earth stations to be located in very rural PEAs in a manner that affects no more than 0.5 percent of the population in these locations, while also adopting a sliding scale for more populated PEAs, resulting in a limit of impacting no more than 0.1 percent of the population in the most populous PEAs.

This additional flexibility is necessary to further the public interest and ensure that 5G broadband services are made available to all consumers in the United States using both satellite and terrestrial networks in more populous communities and using satellite broadband networks in those rural and remote areas where 5G proponents have repeatedly acknowledged they are unlikely to widely deploy.

Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

Bruce A. Olcott
Counsel to The Boeing Company

Analysis of Spectrum Sharing Between

Individually-License Satellite Earth Stations and UMFUS

The Boeing Company

This paper comments on two recent *ex parte* filings by Viasat[1] and Inmarsat/SES-O3b[2] regarding the modeling of individually-licensed satellite earth stations on a shared basis with terrestrial network deployments operating in the Upper Microwave Flexible Use Service ("UMFUS"). The Inmarsat/SES-O3b letter included a draft paper that was developed as a United States contribution to ITU-R Task Group 5/1.

I. The ITU-R TG 5/1 Paper Provides Representative, if not Overly Conservative, Results Based on the Sharing Scenarios Studied

The ITU-R TG 5/1 study submitted by Inmarsat/SES-O3b applies many features of the modeling that are necessary to consider the potential for coexistence between UMFUS and individually-licensed satellite earth stations. Boeing provides in Section IV of this paper a summary of the factors that should be considered in such an analysis. The TG 5/1 study satisfies items 1, 2, 5, and 6 from our list. This is accomplished in part through the use of a statistical model in the TG 5/1 simulation that measures probabilities of interference-to-noise ("I/N") ratios at the satellite earth station using standard propagation models and a 5G beam pointing antenna model specified in ITU-R Recommendation M.2101. The modeling partially satisfies item 3 from our list in Section IV by using a conservative antenna mask (ITU-R 465-6) for the satellite earth station. (The use of the performance of an actual satellite earth station antenna could improve the model.) The T/G 5/1 modeling, however, does not take into account site-specific information such as natural or artificial shielding (our item 4). Likewise, the model does not apply power control in the downlink (but does apply power control for the 5G user equipment ("UE") uplinks).

The TG 5/1 Paper assumes that the terrestrial network deployment (referenced in the paper using the ITU term IMT-2020 rather than UMFUS) uses an urban micro-cell deployment with 6 meter base station ("BS") heights, 1.5 meter UE height, and a cell radius of 100 meters operating within a total deployment area of one square kilometers. The terrestrial network modeling allows for scenarios in which the satellite earth station location is fixed or randomized within the simulation. All BS and UE locations are randomized during the Monte-Carlo trials. The TG 5/1 Paper includes two satellite earth station sizes (1 meter and 6 meters) located at two different heights (12 meters and 4 meters, respectively), which allows for more interference directly into

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[1] "Spectrum Frontiers: Q/V Band Satellite-5G Coexistence," Report by Robertson and Associates, dated Sept 21, 2017, *included as attachment to* Letter from John. P. Janka, counsel to Viasat, Inc. to Ms. Marlene Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177, *et al.* (Oct. 2, 2017) ("*Viasat Paper*").

[2] "Sharing and Compatibility Studies of FSS (Space-to-Earth) and IMT Operating in the 37-50.2 GHz Frequency Range," United States Contribution to ITU Task Group 5/1 (TG5/1), Document 5-1/108-E, *included as attachment to* Letter from G. Creeser (Inmarsat Inc), G. Oberst (SES Americom), and S. Malloy (O3b Limited) to Ms. Marlene Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177, *et al.* (Oct. 12, 2017) ("*TG 5/1 Paper*").

the earth station that is located at a lower altitude. As illustration of these conditions is provided in Figure 1 below.

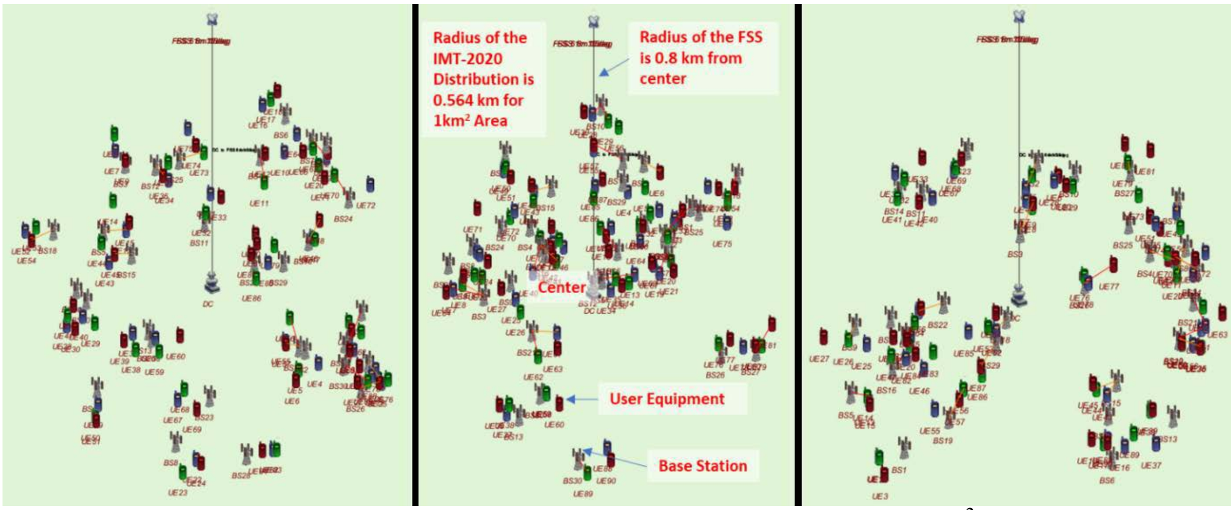

Figure 1 – IMT-2020 and FSS sharing study illustrated[3]

The TG 5/1 Paper evaluates the I/N of the IMT-2020 system interference at the satellite earth station for each earth station type when the earth station terminal is assumed to be operating above either a 10 degree or 35 degree minimum elevation angle. When the satellite earth station location is fixed, the rpaper also presents a parametric evaluation by siting the satellite earth station either 800 meters or 1,100 meters from the center of the 5G deployment. This effectively removes the satellite earth station to outside the operational area of the 5G network.

The results provided in the TG 5/1 Paper for all cases show high confidence (greater than 96% in each case) that I/N target values of -6 dB through -12.2 dB can be maintained. The TG 5/1 Paper concludes for the most stringent conditions that were considered in the analysis (*i.e.*, less than -12.2 dB I/N with greater than 99.9% confidence) that a separation distance of 1,100 meters is required. Given the fact that this distance was measured from the center of the 5G deployment, the acceptable distances from the satellite earth station to the 5G base stations could have been as small as 400 to 450 meters. [4] The results that are provided in Tables 3 and 4 of the TG 5/1 Paper (at offsets of 800 meters and 1,100 meters respectively) show confidence levels of greater than 99.8% of maintaining the target I/N levels. [5] Further, the satellite earth station may be randomly placed *within* the actual 5G urban micro deployment and still experience interference of less than -6 dB I/N with greater than 96% confidence for a 6.8 meter terminal using a 10 degree minimum elevation angle. The results for a 1 meter earth station at an elevated rooftop level using a 35 degree minimum elevation angle show an interference level of -6 dB I/N that is maintained more than 98% of the time. [6] These results, along with the Viasat analysis discussed below, suggest that

[3] *TG 5/1 Paper*, at 6, Figure 5.

[4] *Id.* at 1 and 11, Section 1/1.2.6.

[5] *Id.* at 9.

[6] *Id.* at 8.

satellite earth stations operating in the 37.5-40.0 GHz band can withstand significant 5G interference when site-specific and other advanced suppression techniques are included.

II. The Analysis Provided by Viasat Identifies Additional Opportunities for Spectrum Sharing Using Reasonable and Realistic Assumptions

Viasat provided a separate technical analysis that is largely based on the TG 5/1 Paper, but employs more specific assumptions regarding the satellite earth station deployment and its resulting ability to operate on a shared basis with UMFUS with only minimal separation distances. The Viasat Paper employs a 1.8 meter satellite earth station located on a rooftop at 12 meters in height and operating down to a minimum elevation angle of 35 degrees within an urban micro-cell 5G deployment. This scenario is very similar to the TG 5/1 case of a 1 meter satellite earth station that was also situated at a 12 meter height on a rooftop within a 5G micro-cell deployment. Viasat's paper appears to make only two significant changes to this scenario: i) it increased the satellite earth station size to 1.8 meters (generating an additional 5 dB of antenna gain sensitivity) and ii) it included an additional shielding term of 20 dB isolation due to the blockage effects of the rooftop edge of the building upon which the satellite earth station was assumed to be sited.

The results of these two arguably reasonable changes was to reduce the overall interference terms by a corresponding amount. In other words, the 20 dB of shielding isolation reduced by the 5 dB of additional antenna gain resulted in appropriately 15 dB more isolation for the satellite earth station from UMFUS transmissions. As a result, the I/N levels appear with much lower probability in Viasat's analysis, allowing for substantially higher confidence that the earth station terminal will not exceed the target I/N levels. Specifically, the TG 5/1 Paper reports a confidence level of approximately 97.5% for an I/N level of -12dB,[7] while the Viasat Paper reports a confidence level of more than 99.6% at the same I/N level.[8] This example clearly supports the conclusion that the earth station siting environment resulting from either natural blockage or artificial shielding should be considered as a significant factor in licensing and deploying individually-licensed satellite earth stations. As another example, a 5G deployment operating at higher EIRP levels (for example 15 dB higher than assumed in the Viasat analysis) would still produce interference levels of less than -6 dB I/N with a confidence level of at least 97.5% (or 98.7% if you tolerated -6 dB I/N), the same results indicated in the TG 5/1 Paper.[9] Therefore, the specific conditions of satellite earth station siting should be taken into account rather than arbitrarily imposing explicit prohibitions on satellite earth station deployment in urban areas.

III. Modeling of Sharing Between Satellite Earth Stations and UMFUS Can Be Improved Even Further Using Additional Factors

The scenarios and models presented above are somewhat (though not entirely) agnostic with respect to the type of satellite systems and services (*i.e.*, GSO or NGSO) that are operating

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[7] *Id.*at 8, Table 2, columns 3 and 4 for 1 meter terminal at 35 degree elevation angle; for example, at 50 MHz bandwidth, confidence of *not* exceeding -12.2 dB I/N is (100-2.518) = 97.482%.

[8] *Viasat Paper* at 6, Table 2.

[9] *TG 5/1 Paper* at 8, Table 2, column 3 for 1 meter terminal at 35 degree elevation angle.

with an individually-licensed satellite earth station. The satellite earth station is generally assumed to have an antenna size (with corresponding gain and generally 'fixed' mechanically steered antenna pattern shape) and noise figure, to operate at any azimuth and above a minimum elevation angle. Statistical attributes of the model are largely generated only by the 5G system and its random UE locations, user-to-BS assumptions, with limited use of power control for one link direction. The following items below reflect additional considerations involving NGSO satellite systems (and often GSO systems as well) that can materially affect 5G interference, typically reducing the impact to the satellite earth station such that deployment of additional satellite earth stations may be possible using even smaller exclusion zones, or entirely within 5G deployments.

a) *Inclusion of NGSO beam pointing directions as a variable in statistical simulations*. NGSO FSS earth station pointing beams will traverse skyward paths above minimum elevation angle. This will reduce the periods of time spent at a fixed azimuth or elevation direction likely reducing the overall probability of unacceptable interference.

b) *Modeling of NGSO satellite-to-gateway handover operations and flexible frequency assignment to reduce interference*. Many proposed NGSO systems include inherent redundancy and diversity in gateway coverage offered by the NGSO constellation. The individually-licensed earth stations servicing a given NGSO satellite can potentially be selected to use earth station feeder links that have lower interference from UMFUS networks. Since the largest interference sources (the UMFUS BS and fixed UEs) in a 5G deployment are fixed, it is possible to employ this type of interference reduction strategy.

c) *Use of adaptive nulling or 5G signal cancellation techniques by the earth station*. Though many satellite systems (including NGSO systems) may employ gimbaled dish antennas for large earth stations, the availability of V-band phased-array technologies offers the potential for the use of earth stations based on multi-beam phased-arrays (similar to a large UMFUS BS). Such earth stations operating with NGSO systems are capable of suppressing signals from other co-frequency NGSO FSS satellites as well as localized 5G transmit sources, such as base stations. Digital beamforming implementations offer suppression to the limitations of the array RF hardware (*i.e.*, based on the number of elements in the array and random error limits), which can exceed the typical 35 to 40 dB reflector sidelobe "masks" to achieve 50-55 dBr reflection. Similarly, digital processing in the earth station receiver and the use of signal cancellation techniques (time/frequency domain adaptive cancellation) can also be employed to cancel specific 5G base station signals and to further reduce signals captured within the sidelobes of the array pattern. Systems that offer such capabilities can achieve smaller exclusion zones and may allow larger numbers of individually-licensed earth stations near or within 5G deployments.

d) *Use of power control by 5G transmitters including BS to UE downlink power control*. It can be assumed that beamforming and power control will be used by terrestrial operators in the deployment of UMFUS systems to maximize system capacity and manage self-interference (as well as interference between licensees,

or interference into terrestrial fixed services). Much of the justification for the very high EIRP authorization that was adopted by the Commission for UMFUS BS was based on very low-probability operating conditions, including indoor usage with outdoor-to-indoor (O2I) penetration needs, or large cell sizes/ISDs (*i.e.*, 5G deployed in suburban or rural situations). Appropriate application of power control (even in NLOS propagation or O2I situations) can substantially reduce the effective interference experienced by an individually-licensed earth station. Although the modeling in the TG 5/1 Paper did assume the use of UE uplink power control, no such assumption was applied in the downlink direction. Use of power control is an important parameter given the high EIRP densities authorized by the Commission for UMFUS BS.

e) *Modeling of rain attenuation on 5G and satellite links, along with the joint probability of satellite link degradations*. The TG 5/1 Paper assessed earth station sensitivity and noise floor assuming clear-sky conditions. In rain fade conditions, the additional 5G "noise" has a smaller relative impact on the earth station receiver because the thermal background noise (sky temperature) at the receiver is higher due to the rain fade. The exact impact depends upon the power control employed by the 5G system to address its own localized rain attenuation. For this reason, joint modeling of the rain fade and interference is necessary to determine the expected availability of an FSS downlink in the presence of 5G interference and rain. Further, depending on the design of the FSS satellite (NGSO or GSO), the satellite payload may be capable of applying additional power to interfered links via its adaptive power control systems. The total "power pool" or excess power available at the FSS satellite may be capable of achieving the desired FSS link availability with minimal additional power during 5G mobile transient interference events.

Boeing has performed extensive V-band modeling for the *Spectrum Frontiers* proceeding using rain fade, NGSO FSS pointing and FSS power control, combined with 5G beamforming and power controls, for other interference scenarios. Application of these same modeling techniques by multiple parties can clarify the potential improvements in satellite earth station operations with 5G interference.

IV. Siting Considerations With Respect to Protection of Satellite Earth Stations

As noted at the start of this paper, an appropriate analysis of the reasonable sharing conditions between individually-licensed satellite earth stations and UMFUS systems should at a minimum consider the following factors:

1. FSS earth station protection zones, in particular for NGSO systems, should take into account all valid operational pointing angles from the given location (*i.e.*, all possible operational azimuth angles above a minimum elevation angle). Site

specific fixed (Az, El) pointing information can be utilized for GSO FSS earth stations.[10]

2. FSS earth station protection zone calculations should use available published propagation models from the ITU and recognized standards bodies such as 3GPP.[11]

3. FSS earth station protection zone calculations should use proposed earth station antenna models or data rather than generic compliance masks.[12]

4. FSS earth station protection zone calculations should take into account proposed shielding and/or terrain features as part of the estimated interference levels.[13]

5. Tolerable interference should be defined by using I/N ratios, or the noise floor increase in dB at the FSS receiver due to the interfering UMFUS services and should achieve I/N values of -12.2 to -6 dB, with noise floor increases of 0.5 to 1 dB. The assumptions regarding the FSS earth station and its associated noise figure and background sky temperature should be representative of realistic hardware and expected operating conditions rather than a best-case minimum noise figure using only clear-sky operations.[14]

6. Computation of the noise floor increase should be completed using statistical values for the UMFUS equipment EIRP, locations, and beam pointing directions. A statistical model is generally best suited for calculating the interference levels for a system with mobile users and time-varying beam pointing characteristics. The confidence level for the I/N should be very high (*i.e.*, resulting in a very low probability of I/N exceedances) because the limited number of FSS earth stations that will receive protection from UMFUS transmissions will likely be used as gateway stations with feeder links supporting a large number of users and system capacity. These links require a very high degree of availability and confidence that transmissions will not be degraded.[15]

7. Computations of interference and noise floor increases must also be performed for non-statistical cases. In particular, the operator of a given FSS earth station within a 5G licensee's area should be aware of the locations of all operational UMFUS base stations by all licensees operating within the FSS shared band. Likewise, even given the location of base stations, it may be necessary to perform a worst case analysis to capture UMFUS use cases such as fixed-location (non-mobile) bi-directional links from CPEs to base stations, excluding CPE operations or

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[10] *See Comments of The Boeing Company*, IB Docket No. 17-172, at 2-3 (July 21, 2017).

[11] *Id.* at 5-6.

[12] *Id.* at 6-7.

[13] *Id.* at 8-10.

[14] *Id.* at 11.

[15] *Id.*

connections to certain base stations within a given region surrounding the FSS earth station site.[16]

8. Given the current absence of requirements for UMFUS networks to employ beamforming or power control, it may be necessary for the assumed EIRP density from UMFUS devices to be modeled as worst-case/maximum levels with no power control, with limited antenna sidelobe isolation due to beam pointing. Models with expected UMFUS device antennas (*i.e.*, 3GPP) and power control will provide better performance.[17]

In Boeing's FNPRM comments and reply comments, Boeing noted that numerous analyses have been performed and submitted on FSS earth station and 5G interference, in both the transmit (FSS uplink, *e.g.*, 28 GHz) and receive (FSS downlink *e.g.*, 39 GHz) directions.[18] Even when utilizing similar I/N criteria or a similar 5G deployment model, the results, which are usually expressed in terms of required exclusion zone distances from the FSS earth station, varied greatly, ranging from 50 to 150 meters, with some exceeding 5,000 meters.[19] These variations in results can be attributed in large part to the differences employed in the assumptions listed above. Chief among these assumptions are items 2, 3 and 4 above which when combined with the assumed antenna isolation from the 5G transmit beam (a portion of items 6 and 8) comprise the total signal isolation, or 'coupling' (as described in Viasat's paper)[20] between a 5G transmitter and an earth station receiver. Figure 2 below shows a simplistic budget of the required isolation between a 5G transmitter and FSS earth stations:

[16] *Id.* at 11-12.

[17] *Id.* at 12.

[18] Comments of The Boeing Company, GN Docket No. 14-177, *et al.*, at 20 n.34 (Sept. 30, 2016).

[19] Reply Comments of The Boeing Company, GN Docket No. 14-177, *et al.*, at 29-32 (Oct. 31, 2016).

[20] *Viasat Paper* at 14-15, Figure 11.

5G Transmitter to FSS Earth Station Interference Budget			
5G Deployment Type	UMa	UMa	dBm
5G NLOS Propagation Model	UMa-3GPP	UMa-3GPP	
5G Transmitter EIRP	55.0	55.0	dBmi
Frequency	39.0	39.0	GHz
Transmit Bandwidth	100.0	100.0	MHz
FSS Earth Station Receive Antenna Gain (POB)	55.2	55.2	dBi
FSS Earth Station Noise Figure (NF)	5.0	5.0	dB
5G interference Density (I_0) after FSS peak antenna gain	-126.9	-136.3	dBW/MHz
FSS Earth Station Noise Density (N_0)	-139.7	-139.7	dBW/MHz
Interference to Noise ratio, I/N	12.8	3.4	dB
Desired I/N Ratio	-6.0	-6.0	dB
Effective FSS link degradation (noise floor increase)	1.0	1.0	dB
Total Isolation (coupling loss) Required	**205.9**	**205.9**	dB
Antenna isolation terms	**-58.0**	**-58.0**	dB
FSS Earth Station Sidelobe Level to BS	-35.0	-35.0	dB
5G Mobile Tx Avg Sidelobe level	-20.0	-20.0	dB
Polarization loss (linear to CP FSS)	-3.0	-3.0	dB
Other isolation terms	**-20.0**	**-20.0**	dB
Shielding/site specific attenuation	-20.0	-20.0	dB
Additional FSS Sidelobe level/nulling	0.0	0.0	dB
Additional 5G signal cancellation by FSS receiver	0.0	0.0	dB
5G power control/EIRP reduction	0.0	0.0	dB
Total Isolation (non-propagation losses)	**-78.0**	**-78.0**	dB
Required Propagation Loss	127.9	127.9	dB
Effective 5G to FSS separation required	**352.9**		meters
NLOS probability	94.9%		%

Figure 2 - Example 5G transmitter to FSS earth station interference calculation

It is clear from this table that large total isolation values (in excess of 200 dB) must be achieved in order to reduce the interference from 5G UMFUS emitters into FSS earth stations. Fortunately, a large amount of isolation is available resulting from the FSS antenna sidelobe rejection due to the high elevation angle pointing of the FSS beams. Typical values for the FSS antenna isolation range from 35 dBr to 45 dBr, and perhaps as high as 55 dBr with advanced signal nulling techniques. Similarly good (though lower) isolation values can typically be expected from UMFUS transmitter antenna sidelobes. Values for the 5G antenna isolation and sidelobe levels vary depending on bounding masks or actual values and range from 13 dBr to more than 25 dBr for larger base stations. These values are achieved statistically with in excess of 98 to 99% confidence due to the customary pointing of 5G cellular beams towards intended UE or BS clients and the narrow beamwidths of typical UMFUS transmitters. Finally, a 3 dB isolation is typically used when accounting for linear polarized UMFUS operations versus circularly polarized FSS antennas. Considered together, the antenna isolations can account for about one third or more (around 60 to 80 dB) of the necessary isolation needed for FSS earth station protection.

The remaining isolation (another 100-120 dB) must be accounted for through the remaining factors, specifically: i) localized shielding or attenuation of terrain/buildings and ii) propagation losses such as LOS or NLOS propagation including fading and clutter losses between the 5G transmitter and the FSS earth station. Once a propagation model is selected, the required total

remaining isolation (after antenna coupling and localized shielding is considered) can be translated into a minimum effective distance that must be maintained between the UMFUS transmitters and the FSS earth station. Figure 3 illustrates a number of potential exclusion zone distances that can apply for FSS earth station protection, depending on the propagation models assumed for the same overall antenna isolations and 5G/FSS earth station assumptions. Similar results were illustrated in the Viasat Paper.[21]

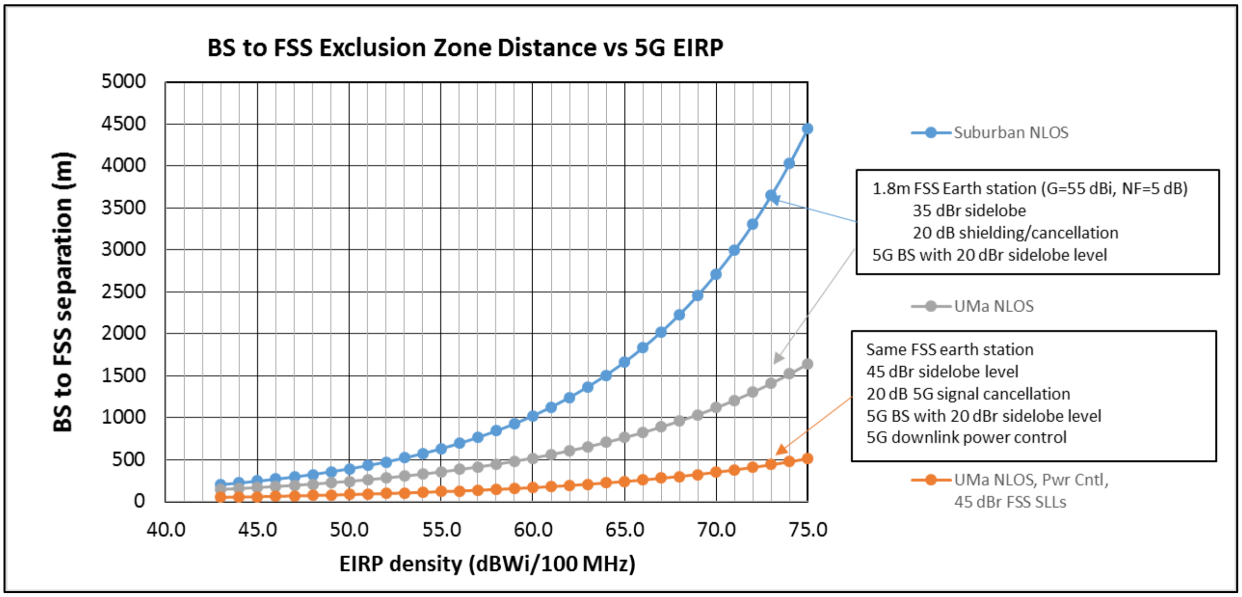

Figure 3 - Example Exclusion Zone Distances for a 1.8m FSS Earth Station

As Figure 3 illustrates, the equivalent distance can be substantially reduced by providing site-specific location shielding, or additional antenna nulling or signal cancellation beyond the antenna isolations already assumed within these curves. The distance can also be reduced if the 5G operations include beamforming and power control in the uplink and downlink directions.

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[21] *Viasat Paper* at 8-1, Figures 5-8.